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Using Global Position Systems (GPS) and Physical Activity Monitors to Assess the Built Environment

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Christopher J. Seeger, Gregory J. Welk, and Susan Erickson

Abstract: *As public health continues to decline and obesity rates hit epidemic levels, there has been increased interest in understanding what characteristics of the built environment may impact the amount of physical activity an individual receives. This paper discusses the utilization of global positioning system (GPS) receivers, physical activity monitors (PAM), meteorological data, and land-cover data to visualize and identify relationships between landscape characteristics of the built environment and an individual's physical activity levels. This paper showcases a procedure for synchronizing the collected data, describes pitfalls to avoid when conducting a study, and illustrates how the results can be analyzed and visualized in a geographic information system (GIS).*

INTRODUCTION

According to the Centers for Disease Control (CDC), approximately 66 percent of the U.S. adult population is either overweight (body mass index of 25 to 29.9) or obese (BMI >= 30). These percentages are approximately twice the amount reported in health surveys taken in the mid-1970s. While there is debate regarding if this increase in prevalence constitutes an epidemic, it is widely accepted that insufficient individual physical activity and exercise is one of the contributing factors to weight gain. The CDC's Behavioral Risk Factor Surveillance System (BRFSS) found that in 2005 the national average of individuals participating in the recommended amount of weekly physical activity was only 48 percent, while 37.7 percent reported an insufficient amount of activity and 14.2 percent reported they were inactive. Another study reported that "sixty-two percent of adults never participated in any type of vigorous leisure-time physical activity" (Pleis and Lethbridge-Çejku 2006).

The fact that more than half of the U.S. population does not undertake a sufficient amount of physical activity calls to question why more people aren't physically active when many communities have been investing significant funding to improve the outdoor infrastructure (parks, ball fields, trails) that facilitates and promotes opportunities for physical activity?

This and other similar questions have brought to the forefront investigations into how the built environment affects an individual's participation in leisure-time physical activity. The executive summary for the 2004 "Obesity and the Built Environment: Improving Public Health Through Community Design" Conference in Washington, D.C., found that the "rapid increase in obesity over the past 30 years strongly suggests that environmental influences are responsible for this trend."

Report #282, Does the Built Environment Influence Physical Activity: Examining the Evidence, published by the Transportation Research Board in January 2005, states that there is "available empirical evidence" linking a person's physical activity with the built environment. The report further states that additional studies into the "causal relationship between the built environment and physical activity are needed" and that future research should include "residential location preferences, and characteristics of the built environment as determinants of physical activity."

To identify, visualize, and understand this relationship between physical activity and the built environment, spatial analysis and data collection tools such as geographic information systems (GIS) and global positioning systems (GPS) can be used. These tools can provide an accurate map with which proximity, distribution, and connectedness can be measured. And, when combined with physical activity monitors and employed in participatory supported research, they can become even more useful measures.

The remainder of this paper focuses on one component of a study investigating the relationship between physical activity, trail use, and adjacent vegetation. In this component of the study, spatial, individual physical activity, and weather data were collected and processed and then visualized and analyzed in context with the built environment.

PROJECT BACKGROUND

To better understand the role that vegetation or, more specifically, the urban forest has on an individual's selection and use of community recreation trails, the National Urban and Community Forestry Advisory Council funded a study by Iowa State University Extension to investigate the relationship between vegetation patterns and physical activity. The research, conducted between July 2005 and July 2007 in Ames, Iowa, sought to answer the following questions:

- Does vegetation adjacent to a trail impact the use of the trail?
- Is vegetation variety an important aspect of route selection?

- What role do trees play in trail selection in various weather conditions?
- What are the characteristics of the most commonly used trail segments?
- Do physical activity rates (exertion) correspond directly to the adjacent landscape, trail surfaces, or trail length?

Research Framework

Information for the study was collected from 48 Ames residents who identified themselves as physically active adults who walked or ran at least three times per week on community recreational trails. These participants were selected from a pool of 500 people who responded to a request for participants. Selections were based on gender, age, and location of residence. Study participants fell into one of three population age groups: 18–30, 30–55, and 55+.

The study lasted one year and included four one-week data-collection periods during the months of November, January, April, and August. For each of the one-week periods, each participant was asked to wear a GPS device on the wrist when he or she was walking or running. Participants also wore physical activity monitors attached to their waistbands for the entire week of the study during waking hours. In addition to wearing the two devices, participants kept paper logbooks documenting their daily physical activities. Each study week started at 12 A.M. on Wednesday and concluded at 11:59 P.M. on the following Tuesday.

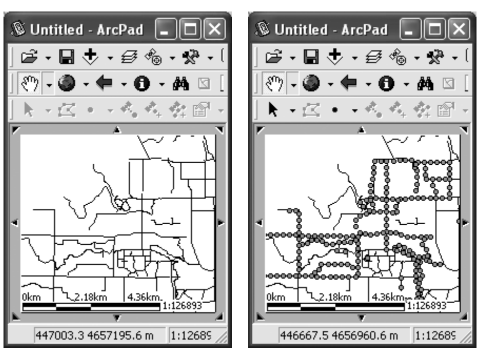


Figure 1. ArcPad screen displaying road network and trail sample points.

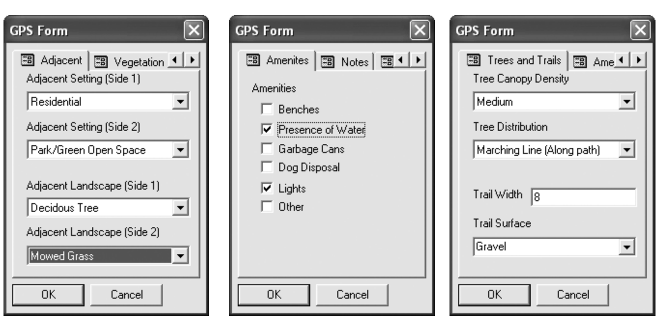


Figure 2. ArcPad inventory forms.

To answer the research questions presented in the study, it was necessary to collect and identify:

- Which trails were used.
- When the trails were used.
- What the weather conditions were at the time the trails were being used.
- How much physical activity was exerted as individuals used the trails.
- The characteristics of the trails and their adjacent landscape.

Data collected from GPS devices worn by the participants were used to identify which trails were used and when the trails were used. Minute-by-minute weather data was collected at a local elementary school's weather monitor and archived to a server on the Iowa State University campus. The physical activity monitors (or accelerometers) worn by the participants recorded the amount of physical activity they received during each minute of the day. The existing characteristics of the trails and the adjacent landscape were identified using field observations that were recorded with a GPS and inventory form. A community-wide vegetation map also was created from one-foot resolution aerial photography.

The study was approved by the university's Institutional Review Board and all participants signed letters of consent before participating in the study. At the end of the study, participants were allowed to keep the GPS devices.

DATA-COLLECTION DEVICES AND PROCESSES

While basic infrastructure GIS data existed for the community, the majority of the data was at a scale that was not detailed enough to reveal characteristics of the built environment that may influence physical activity. Therefore, it was necessary to collect much of the information in the field or by digitizing high-resolution aerial imagery. For the purpose of identifying route preference or physical activity, a participatory approach using GPS and physical activity monitoring devices was utilized to collect the data.

Adjacent Landscape Inventory

Two data layers were created to inventory the environmental characteristics of the study area. The first data layer contained the trail characteristics and adjacent vegetation information and was created in the field using Trimble's pocket pathfinder GPS and an HP iPaq PDA running ESRI's ArcPad 6 software. The ArcPad/PDA solution allowed a base map containing the road and trail network to be displayed along with the location of sample points that were prelocated based on a linear sampling distribution of 100 meters (see Figure 1). Two graduate students walked each of the trails and stopped at each of the sampling points to photograph and record the vegetation adjacent to the trail as well as characteristics of the trail.

Figure 3. Garmin Foretrex 101.

The field-data collection process was simplified by using form fields organized by content across six GPS inventory pages. The first page, adjacent land setting/land use, included pull-down menus for selecting the correct characteristics of the trail's adjacent environment. Because the land use and landscape may differ for each side of the trail, each side was included as a unique attribute. Side 1 represented land that was north and east from the trail. Side 2 represented land that was south and west from the trail. The additional form pages included vegetation cover, tree characteristics, trail surfaces, amenities, and notes (shown in Figure 2).

The GPS used for the data collection had an accuracy of two to five meters when combined with a real-time differential correction source or differentially postprocessed; however, in this study, the data was collected without any differential correction at an accuracy of approximately ten meters. This level of accuracy was sufficient for the study, the sampling points were prelocated using aerial data with a resolution of less than one meter; thus the GPS-enabled PDA was primarily used to navigate to the general location to complete the form.

Participants in the study did not always walk or run for leisure exclusively on designated trails, making the data collected at the sample points insufficient for analysis of entire routes. A community-wide land-cover layer was therefore necessary. The existing land-cover data for the community was limited to a 15-meter resolution data set that was interpolated from color infrared aerials flown in 2002. This resolution was not adequate for the study so the city's submeter photography from 2003 was digitized to create a more accurate vegetation map. The land-cover layer included four categories: deciduous, coniferous, agriculture fields, and water.

Participant Location—GPS

The GPS device selected for study participants to wear was the Garmin Foretrex 101 (see Figure 3). This GPS was selected because it provides an affordable receiver that is lightweight with

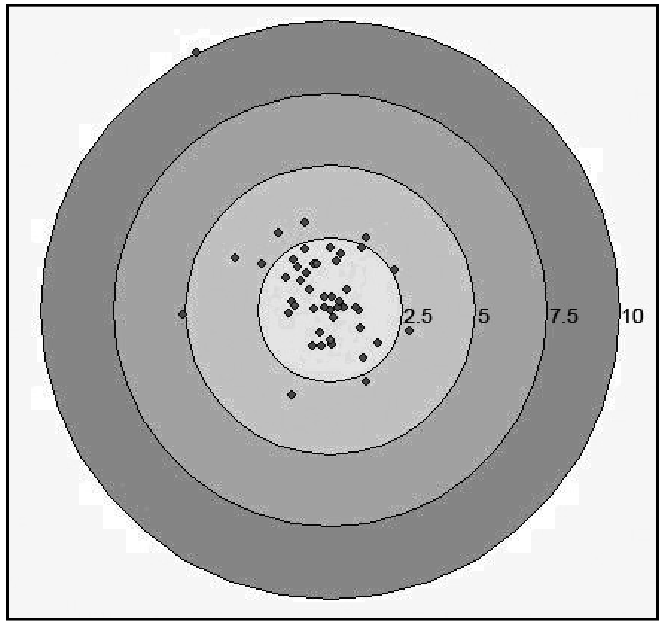


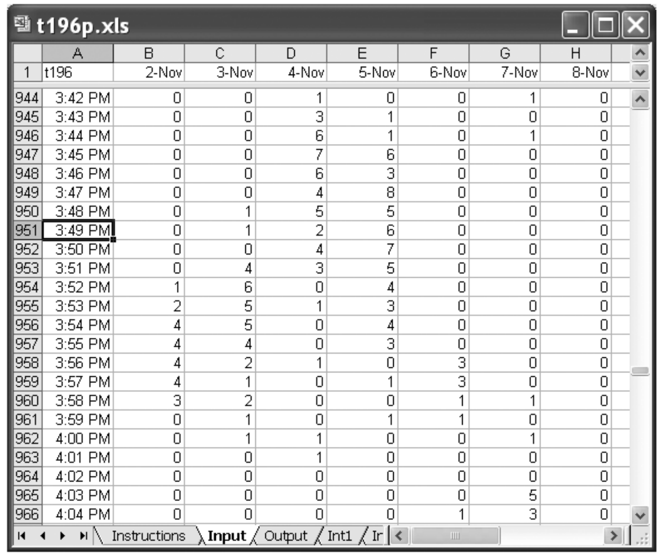
Figure 4. Garmin Foretrex 101 accuracy test.

a small form factor and good accuracy. Costing under $125 per unit, the Foretrex 101 was one of two models in the initial series of wrist GPS units by Garmin. The other model, the Foretrex 201, offered the same functionality as the 101 model but used rechargeable batteries instead of the two AAA batteries used by the Foretrex 101. The higher price tag of the Foretrex 201 and the requirement to recharge the batteries made it an unsuitable option for this study.

The small size and light weight of the device made it easy for participants to use it without being distracted. The Foretrex 101 measures 3.3 inches wide, 1.7 inches high, and 0.9 inch deep (8.4 x 4.3 x 2.3 cm.). The device weighs only 2.75 ounces (78 grams). The controls are located on the front edge of the device and are easy to operate. For the purpose of this study, participants only had to turn the device on and off.

Spatial accuracy was an important requirement of the selected device, and the Foretrex 101 met the required need for it was accurate to approximately ten meters or less. The device is Wide Area Augmentation System (WAAS) compatible, and with WAAS turned on the accuracy averages around three meters. WAAS uses a system of satellites and ground stations to provide signal correction to the GPS, making it much more accurate than standard GPS devices. Prior to the start of the study, 47 of the devices were tested for accuracy by concurrently laying them on the ground at a known geodetic point and collecting data for a period of ten minutes after the units had warmed up. The study itself introduced an error of approximately nine inches since all units could not be placed at the center of the known point concurrently. By testing the devices at the same time, it was possible to identify satellite reception and to average the recorded locations. The test found that 36 of the devices had an average location within 2.5 meters of the known point, 9 devices were between 2.5 and 5 meters, 1 device was between 5 and 7.5 meters, and 1

Figure 5. IM Systems Biotrainer-Pro.



t196p.xls

	A	B	C	D	E	F	G	H
1	t196	2-Nov	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov	8-Nov
944	3:42 PM	0	0	1	0	0	1	0
945	3:43 PM	0	0	3	1	0	0	0
946	3:44 PM	0	0	6	1	0	1	0
947	3:45 PM	0	0	7	6	0	0	0
948	3:46 PM	0	0	6	3	0	0	0
949	3:47 PM	0	0	4	8	0	0	0
950	3:48 PM	0	1	5	5	0	0	0
951	3:49 PM	0	1	2	6	0	0	0
952	3:50 PM	0	0	4	7	0	0	0
953	3:51 PM	0	4	3	5	0	0	0
954	3:52 PM	1	6	0	4	0	0	0
955	3:53 PM	2	5	1	3	0	0	0
956	3:54 PM	4	5	0	4	0	0	0
957	3:55 PM	4	4	0	3	0	0	0
958	3:56 PM	4	2	1	0	3	0	0
959	3:57 PM	4	1	0	1	3	0	0
960	3:58 PM	3	2	0	0	1	1	0
961	3:59 PM	0	1	0	1	1	0	0
962	4:00 PM	0	1	1	0	0	1	0
963	4:01 PM	0	0	1	0	0	0	0
964	4:02 PM	0	0	0	0	0	0	0
965	4:03 PM	0	0	0	0	0	5	0
966	4:04 PM	0	0	0	0	1	3	0

Instructions | Input | Output | Int1 | Ir

Figure 6. Sample downloaded physical activity counts with timestamp.

device was just over 10 meters (see Figure 4). In the case of the device that was more than 10 meters, it was determined that the WAAS feature was not enabled. The findings of the accuracy tests were in line with what Daniel Rodriguez reported for accuracy tests of the Foretrex 201 where he found the "average distance recorded from the units to the geodetic point was 3.02" meters with 81.1percent of the 726 GPS points collected (Rodriguez, Brown, and Troped 2005).

The other critical feature in the selection of the GPS was the capability to store a tracklog that could record where the participant walked or ran. The Foretrex 101 is capable of storing 10,000 points and can be set up to record at intervals as short as one second. The study utilized a ten-second interval, sufficient for recording points every 220 feet (67 meters) for a fast four-minute mile or every 44 feet (13.4 meters) for a person walking an average three miles per hour. At this setting, it would take more than 27 hours of use to fill the tracklog.

An optional Db9 interface cable provided a method to download tracklog records to a computer with a serial port. Each downloaded tracklog file contained the latitude, longitude, UTM coordinates, elevation, and time-stamp for each point recorded during a physical activity session. The tracklog also contained a field indicating when the device was turned on and when new data was being appended to the tracklog. The time-stamp recorded by the tracklog included the date and time as a single field value. The time stamp was stored in the year/month/day-hour:minute:second (2005/11/02-22:02:56) format.

The primary limitation of the Foretrex 101 was its battery life, which was specified to last 15 hours. Because of the increased power consumption of the WAAS, however, the average life was closer to 12 hours. In extremely cold temperatures, the battery life was dramatically reduced and the devices would often turn off after less than 30 minutes of use. Because of the limit imposed by the battery life, participants were asked to only wear the GPS when they went outside for a walk or run.

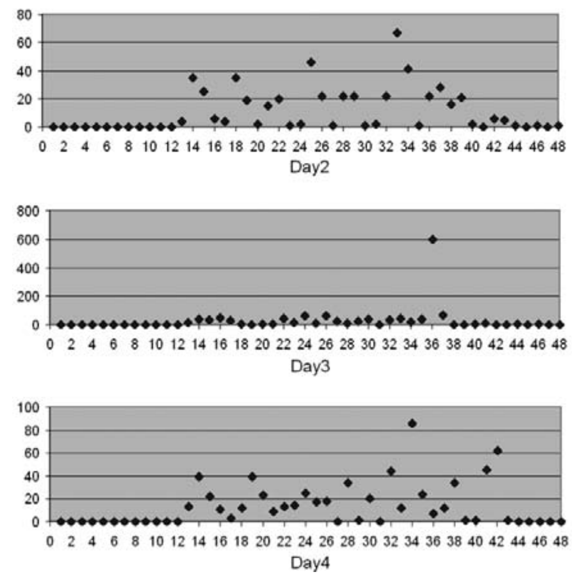


Figure 7. Sample physical activity data graphed in 30-minute intervals.

The GPS came with a wrist strap that allowed the participant to wear it strapped to his or her body. As reported in the findings by Rodriguez et al., the location of the device on the body does impact the quality of the collected data and it was recommended that the devices be worn on the wrist (Rodriguez, Brown, and Troped 2005). Participants in this study were instructed to wear the devices on their wrists over clothing (extender straps were provided) with the LCDs facing up.

Physical Activity—Accelerometer

Accelerometry-based activity monitors are used to measure physical activity in free-living environments. Physical activity monitors

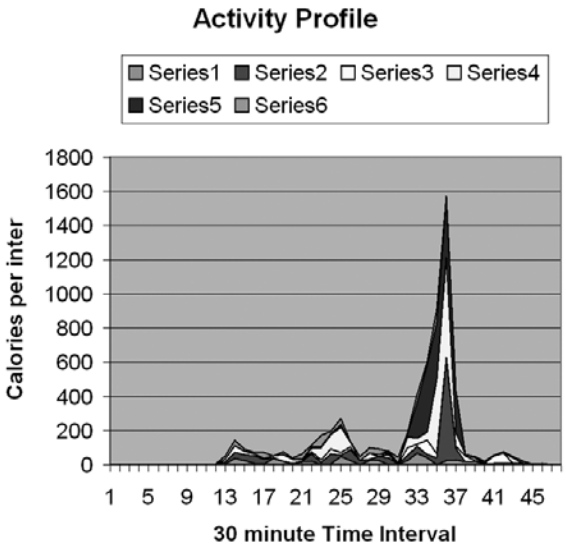


Figure 8. Sample physical activity calories used graphed over 6-day period.

(PAMs) are a preferred measuring device in health research because they can digitally record physical activity as numeric values over a specified period of time. "Physical activity monitors can be worn without major inconvenience" and are compatible with most daily activities requiring little effort on the part of the user (Slootmaker et al. 2005).

The PAM selected for this study was the BioTrainer-Pro by IM Systems (shown in Figure 5). The primary reason for its selection was that 50 devices were already available at Iowa State University and they had been found to be reliable devices. The BioTrainer-Pro uses a biaxial acceleration sensor for measuring a full range of body movements. Collected data can be recorded to the device's memory at intervals ranging between 15-second to 5-minute epochs. The data is stored using absolute "g" units. For this study, data was collected every 60 seconds; the device can hold 22 days of information at this setting.

The BioTrainer-Pro uses standard AAA batteries and the data can be downloaded to a Windows computer for analysis. The downloaded data includes a count value representing the amount of physical activity since the last interval point and a relative time stamp showing the amount of time passed since the device was initialized (see Figure 6). This data can be graphed to show the amount of physical activity an individual undergoes over a series of days (shown in Figure 7), where the values are summarized in 30-minute intervals. The data also can be viewed with several days overlapping, as illustrated in Figure 8, or over the entire four study periods, as shown in Figure 9.

Daily Weather Conditions

Minute-by-minute weather conditions as recorded at an Ames elementary school were archived and saved to the Iowa State University Department of Agronomy's Iowa Environmental Mesonet server (http://mesonet.agron.iastate.edu/schoolnet/dl/).

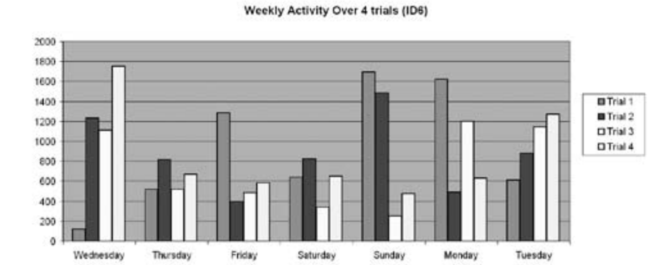


Figure 9. Sample weekly physical activity graphed over 4 trial periods.

STID	DATETIME	tmpf	dwpf	drct	sknt	pday	pmonth	srad	relh	alti
SAMI4	11/2/2004 22:05	35	34	360	0	0	0.8	0	98	30.32
SAMI4	11/2/2004 22:10	35	34	360	0	0	0.8	0	99	30.32
SAMI4	11/2/2004 22:15	35	34	360	0	0	0.8	0	99	30.32
SAMI4	11/2/2004 22:20	35	34	360	0	0	0.8	0	99	30.31
SAMI4	11/2/2004 22:25	35	34	360	0	0	0.8	0	99	30.31
SAMI4	11/2/2004 22:30	35	35	360	0	0	0.8	0	100	30.32
SAMI4	11/2/2004 22:35	35	35	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 22:40	34	33	250	0.87	0	0.8	0	100	30.31
SAMI4	11/2/2004 22:45	35	35	315	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 22:50	35	35	290	0.87	0	0.8	0	100	30.31
SAMI4	11/2/2004 22:55	35	35	315	0.87	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:00	35	35	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:05	34	33	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:10	34	33	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:15	34	33	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:20	34	33	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:25	33	32	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:30	33	32	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:35	33	32	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:40	33	32	360	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:45	33	32	315	0	0	0.8	0	100	30.31
SAMI4	11/2/2004 23:50	33	32	360	0	0	0.8	0	100	30.31

Figure 10. Sample downloaded weather conditions.

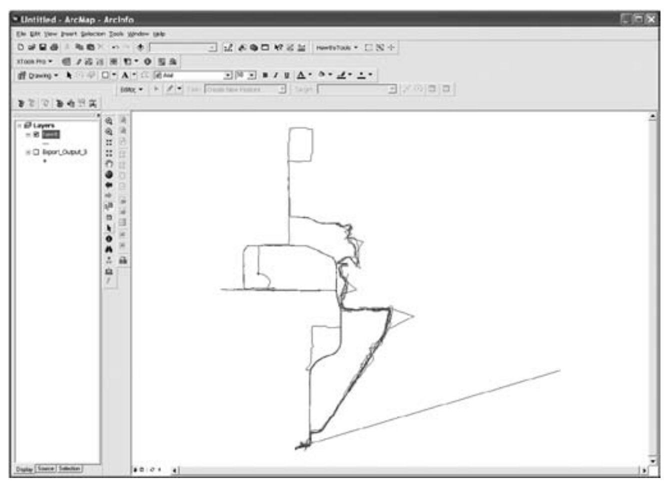


Figure 11. GPS error identification shown as sharp corner points.

From this server, various data parameters could be downloaded as a delimited file (shown in Figure 10). The data parameters included air temperature, wind direction, dew point, wind speed, relative humidity, solar radiation, and altimeter (pressure). Each row of data also contained a time-stamp field in month/date/year 24 hour:minute format (11/2/2004 22:10).

PROCESSING THE DATA

At the end of each study week, data from the GPS and physical activity monitors were downloaded, cleaned, reviewed for errors, and then processed so they could be displayed in a GIS.

Data Cleaning

After the tracklogs were downloaded from the GPS, the data were trimmed to only show recorded values within the seven-day study period. Points recorded outside the study area also were trimmed for in some cases the participants wore the GPS when using one of the countryside recreational trails. The physical activity monitor data also were trimmed to only show the data collected over the seven-day period. Trimming the data of both devices reduced the number of points to be synchronized and made the files easier to manage.

Error Checking

Potential error could be introduced into the study in one of three ways. The first error was created when the GPS itself collected an incorrect point. As illustrated in Figure 11, spike points would result on the map when an incorrect point was recorded. Observational and mathematical techniques were used to identify these locations. The observational method simply required displaying the point in ArcMap and creating a line feature that connected the points. Line segments that resulted in a sharp point were considered suspicious and were marked as such. The mathematical method calculated the average distance between points to identify the speed required to get from point A to point B in ten seconds. If this speed was significantly higher than the speed calculated for the previous two points, the points were identified as suspicious. All points identified as suspicious were either deleted or manually relocated to where they were geographically expected to be based on the location of previous and future points.

The second error was introduced by the participant. While participants were instructed to only wear the GPS units when walking or running, the devices on occasion were turned on when the participants were driving or riding bikes. Once again, speed and distance traveled calculations were utilized to identify these suspicious points. The process of error checking was aided by the paper log of physical activity that each participant kept. On the log sheet, a participant recorded the time of day that he or she walked or ran and whether or not he or she was wearing the physical activity monitor or GPS.

The last area for significant error to be introduced was in the process of preparing the physical activity monitors for each study period. Because the relative time saved in the monitor was critical for data synchronization, all monitors had to have the same base point for starting their internal clocks. To accomplish this, all monitors were initialized on a computer that had its time synchronized with a Network Time Server that was in alignment with the time recorded on the GPS.

Data Synchronization Process

The time stamp was the key to synchronizing the data collected from the GPS with the physical activity monitor. The time stamp also provided a means for synchronizing the downloaded weather data with the spatial data. The data downloaded from the physical activity monitor determined the format to be used for synchronization for the data were saved with each column representing a day and each row the number of minutes past midnight. For example, row 877 (minus one for the header) of

Figure 12. Recorded data for one participant over four study periods. Larger dots represent an increased level of physical activity.

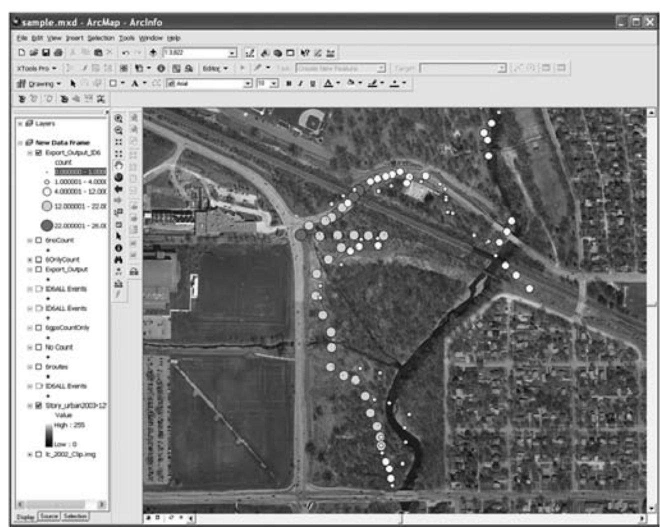


Figure 13. Data display limited to only show physical activity counts of 1 – 26 where red/larger dots represent the highest level of physical activity recorded.

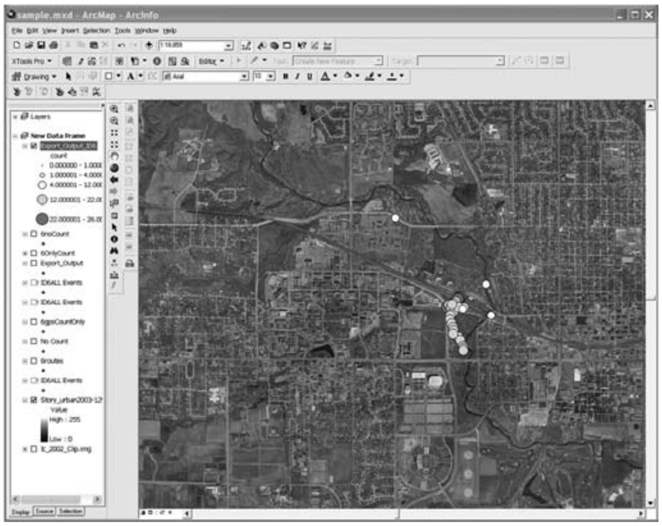


Figure 14. An individual's data limited to physical activity values greater than 4 indicated the majority of their intense physical activity took place in a wooded park area.

column 2 represented 2:36 P.M., so a value of 876 could be applied to that time. This same conversion format was applied to the GPS and weather data. The time stored on the GPS was in Universal time, requiring a value of 300 (or 360 depending on if daylight saving time was in effect) to be subtracted to correct the value to Central time (see Table 1). Once the time stamps were converted to a uniform format, the data were merged (joined) together and added to ArcMap.

Table 1. Time stamps calibration for time since midnight

Data	Native Format	Converted Format
Physical Activity Monitor	(col2) 2.36 PM	0876
GPS	2006/02/14-19:36:22	1176 – 300 = 876
Weather	02/14/2006 14:36	876

Data Visualization and Analysis

Once synchronized and merged into a single file for each study participant, the data were overlaid on the aerial photograph and vegetation data layers in ArcMap. With the data symbolized based on physical activity values, it was possible to identify not only which trails the participant used, but how much physical activity they exerted since the last recorded point. Figure 12 shows the trail-use patterns recorded over the length of the study for one participant. An increase in physical activity is illustrated using larger dots. Figure 13 shows a closer look at one of the areas the participant occupied when high physical activity counts were recorded. Figure 14 illustrates that the majority of the highest values included in any of the four trial periods for this participant occurred in or near parks on paved asphalt trails.

The samples provided in Figures 12 to 14 present data from just one participant**.** However**,** within the study, the data from all participants were analyzed to locate relationships between the built environment and physical activity. Various spatial analysis techniques including proximity overlap and zonal statistics were utilized to identify the most commonly used routes, existing trails that were underutilized, patterns of vegetation, and locations where physical activity values increased/decreased. The time-stamp value also allowed the data to be queried to only show the activity of the entire study group for a specific time of day. The weather conditions at the time of use were available as contextual information from the table or as a data query parameter.

CONCLUSIONS

This paper presents a methodological framework for visualizing and analyzing the relationships between the built environment and physical activity using data derived from participants' interactions with the built environment. When viewed individually, the data-collection devices discussed present only a piece of the information that is necessary to understand the relationship in question. However, when the data from each device are synchronized and merged with other environmental data, a more complete model of the environment can be visualized and analyzed. This technique can be applied to many research areas as multiple characteristics of the built environment are evaluated. Throughout the study, several lessons were learned that should be considered when conducting future studies:

The use of a paper log file is a necessity for it helps identify where participants did not follow the study protocol or the GPS device failed to acquire a good signal.

Erroneous data can and will be logged by the GPS when the signal is lost or the participant steps indoors or under dense tree canopy. It is therefore necessary to clean and check all recorded data.

The BioTrainer-Pro device includes a plastic clip for securing the device to the participant; however, the clip often failed so an elastic band with an alligator clip was used as a secondary method to ensure that the device was not lost. Participants should take care when using the restroom or changing clothes; the shuffling makes it easy for the devices to fall off.

The Foretrex GPS included a wrist-band extender that worked very well except during the January trial period when it was not long enough to be worn on the wrist over winter clothing. Participants were tempted to wear the unit under their clothes, which resulted in weaker signal reception.

The batteries selected for the study performed poorly during the coldest days of the January study period. While all the batteries were new at the beginning of the week, several battery exchanges were required. This problem did not exist in the following two trial periods. Research conducted during cold periods should utilize premium quality batteries capable of maintaining a charge when exposed to freezing temperatures.

The BioTrainer-Pro device used during the study included an LCD display that showed the count value. In some cases, an LCD would turn off during the study and the participant thought the device was not working so an exchange was made.

Upon examination it was determined that the device was still recording but the display had malfunctioned for an unknown reason. The end result was that two data sets had to be merged together. The recommendation is to turn the display off during initialization of the device.

Throughout the study, the same GPS units were assigned to the participants. This was not the case with the BioTrainer-Pro units, which resulted in an extra step of data management before the data could be synchronized.

Acknowledgments

Greg Welk, Ph.D., Co-PI—accelerometry-based activity monitor data and analysis; Susan Erickson, ASLA, Co-PI—participant organization and data logs; Khalil Ahmad, graduate student—GPS data and device management; and Zoran Todorovic, graduate student—ArcPad form development and data collection.

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